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ABSTRACT

A systematic study was conducted with a group of 10- to 12-year-olds using computer assisted instruction in a unit on fire which included a computer simulation of combustion. Three research questions were addressed to learn more about how the computer experience challenged the students' preconceptions: what the students thought the computer knew, what they knew about burning, and how they learned from the computer. Sixteen students were interviewed about the actual study of combustion (by putting candles in jars) and the simulation of this process on the computer, and their attitudes toward classroom experiments versus computer simulation were noted. The students' responses were analyzed to examine the interaction between real and simulated science experiments and ways in which each can be used to stimulate concept formation and conceptual development in science. Results indicate that teaching methods that rely solely on computer simulation may overlook the fact that students have preconceptions concerning science which must be addressed in order for learning to occur. It is concluded that, although simulations can contribute to conceptual change, they must be used in conjunction with traditional teaching methods. (DB)

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COMPUTERS AND CONCEPTUAL CHANGE*

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COMPUTERS AND CONCEPTUAL CHANGE

Conceptual Change in Science

In a systematic study of 10 to 12 year olds, we probed in depth how computer-based learning influence conceptual change in science (Olson and Pothaar, 1988). The questions we had in mind was epistemological as well as logical: what did students think the computer knew, and what did they know about burning and how did they learn from the computer? We wanted to know more about how the computer experience challenged student's pre-conceptions.

In order to do this two teachers of junior pupils (ages 10-12) and myself, with the help of a research associate, designed an integrated unit on Fire in which the computer simulation of combustion FLAME LIFE (Olson, 1984) was a part. The students studied myths about fire, fire and technology, as well as combustion and the mathematics that went with its investigations for real and through simulation. We interviewed 16 students about the actual study of combustion (by putting candles in jars) and the simulation of this process on the computer. This paper is based on an analysis of what these students said. In this paper I want to look at how the interaction between real and simulated experiments might be used to stimulate conceptual development in science.

Student Perceptions of CAI based Science Learning

The Experimental Process. Students said that flame, smell, smoke, heat colours and light were products of combustion. They focused on the observable entities of the process. These are the things the computer was not able to simulate, but are what students notice about the process. Students were asked to say what they

thought smoke was. Smoke was dust, ash, something that uses up oxygen -- the stuff that "comes off" from burning. Smoke was a solid thing, rather than being a gas. The candle itself melts in the burning process and if that melted wax is collected the candle can be restored if a wick was added. All but one agreed that you could restore the candle this way.

Kate (11) said when a candle burns it gets smaller and smoke is given off which comes from the wax. Jeremy thought that carbon dioxide was given off. The smoke comes from the "burned up" oxygen and also from the wick. The wax turns to liquid. Some of the wax is still there but a "missing bit would have gone up in the air." Colin said the flame gave off light, heat, smoke and odor. Smoke is burnt oxygen. The wax melts but is not burned. The candle could be made again out of the melted wax.

The products of combustion are carbon dioxide, heat, light and smoke. Smoke is ash from the wick, and the burnt wax. It is burnt oxygen. The candle could not be reconstituted from the melted wax. Some of the wax is consumed in the burning process, as Laurene (12) suggests:

You wouldn't get as much -- half would be missing. It has burned into smoke -- maybe into carbon dioxide. It has gone from solid to liquid to gas.

The students are agreed that the wax has been burned and has undergone a change of state into smoke or carbon dioxide. The students have a clearer idea about the invisible processes that account for the things they can see. The rudiments of a chemical theory of combustion are at work in their explanation but none of them appears to have it clearly in mind that the stuff of wax combines with the oxygen to form carbon dioxide. Their descriptions of the process are still tied to everyday language and to surface phenomena. Nonetheless the basic idea of combustion is imminent in what they say.

Simulation vs. The Real Thing. The students were asked again to compare computer results to their own results from the actual experiment. If there were differences, which would they trust?

One thought the actual experiment should be trusted, two thought the computer and one thought both. Here is what 10 year olds said:

I'd believe the one [real experiment] that we did. We did the actual thing.

The computer, I think, because the computer has very precise timing. If you were not watching your watch

Probably the one on the computer. The person that was making the programs checks it over a few times... I might not have timed it properly. Somebody, could have not put the program in right. I might not have looked at my graph right.

Kate (11) thought the real experiment should be trusted, even though you could make a mistake in timing the candle but "in the class most people get the same answer most of the time so you felt you were right." Jeremy thought the actual experiment should be trusted because "you've done it and you can tell what it's going to be ... because you've got control." Colin (11) said the same, because "computers are sometimes wrong; if you do it in real life it would be realistic and you could believe it easier.... If the computer is programmed wrong, it could be wrong every time. [Humans] don't make the same mistake again; they learn, but the computer doesn't."

Colin J. (12) trusted what he called "real numbers;" "I'd go with the real numbers because the computer can make a mistake; ... in the computer if it makes a mistake once it usually will make it again, but if you make a mistake you can correct yourself." Collin thought the real thing more exciting: "On the computer you don't have the feeling of actually being able to do it yourself. [In the real thing] you actually have a feeling of saying I feel great; I got this right. The computer didn't do it; I did all the work!"

Laurene (12) also trusted the real experiment, because even though she could make a mistake, so could the person programming the computer. "The computer could keep on making the same mistake." Katherine (12) thought the same. The computer could be wrong. Paul said that he would trust the real thing: if you are good ... you could be sure you did it right." Michelle was with the rest; the real experiment is to be trusted, because it is real.

Students were asked to compare actual and simulated experimentation. How did they differ? The 10 year old students commented on the range of choice of containers and candle sizes. The built in timing, the graph, the safety, the predicting provided by the computer. However the computer did not have the real colours, the smoke, the flame going out, the swell and the melting wax of the real experiment, and the computer restricted the size of the container.

The 11 year old students said that the computer did not show the candles floating in a tray and that there was no smoke, nor melting wax. They also noticed that the container was only a sketch and that the trial times varied in the real experiment, but not on the computer. However, the computer does the experiment at the push of a button, they said, and you can predict, you can pick many beaker sizes and get a graph.

Colin J. (11) thought timing of the computer was less accurate than the real experiment (since he had used a stop watch with 1/10 second timing). He thought the computer could make mistakes by being mis-programmed. On the computer the candle didn't "fizzle." Laurene found just pressing button 'fake.' Katherine said real candles and real jars were missing and in the actual experiment you could watch it happening. Paul missed the "action," and found not having to set up the experiment unreal. He wasn't sure about the computer results. Michelle missed the 3-

dimensional character of the actual expressment.

On the other hand, Colin J. liked the idea that the computer could graph the results, that it gave a choice of containers and numbers of candles and was safer. Laurene also liked the choice, the graph, the built-in timing and not having to set up the experiment. Katherine agreed that the experiments were easier to do on the computer. She liked the graphs as well. Paul also thought that the experiment was quicker to do on the computer and he liked the graph. Michelle thought the built-in timing useful, being able to make predictions was a good experience and they too liked the graph but wished that the computer could print it for her.

We found that the older children had a more developed appreciation of the "power" of the computer, but also as we have seen, a better idea of the limitations of computer programs. These students appreciated that the very virtues of the simulation are the same as its defects. It is quicker to do things using the simulation, but unreal because you only have to push a button. All said they liked to see a graph of their results.

The Conceptual Change Process

Clues to Conceptual Change. The 10 year old students are impressed by the precision of the computer and aware of errors they might make. Yet the computer could make a mistake as well, they said, if it wasn't programmed properly. On balance, the computer is to be trusted. Although the computer is precise, it does not provide the sensations that students pay attention to in trying to make sense of what they observe. They attend to the obvious features of the process: smoke, a rather solid substance is given off and the candle melts. The underlying processes are not apparent which leaves the idea of oxygen being used up, which they all affirm, in a kind of limbo.

The 11 year old students were impressed by the push-button ease of the computer and its range of choice and graphical display, but noticed that elements of the actual experiment *design* were missing as well as the products smoke and smell. They expect the system to behave according to their pre-conceptions and were puzzled by the failure of the computer to confirm their expectations about the effect of candle size on burn time. Understanding the process of combustion depended less on obvious features -- it included non-observed entities and processes. But students were not clear just how these entities fitted together in a process.

The 12 year old students think a computer cannot learn from mistakes as humans can. The computer goes on and on reflecting the original mistake while they, the humans, are able to detect their mistake. They are the "smart" ones. The grade 4's on the whole trusted the computer; the 6's trust the humans. They appear to have a better idea about the limitations of machine "intelligence", or lack of it.

What are the trends here? We can see the shift in trust from computer simulation to human controlled experimentation. There has also been a shift from a perceptual to conceptual understanding of combustion. The 10 year olds explain the process in terms of readily observable entities -- the 12 year olds use non-observable entities in explanation and link observable entities together in logical strings. Thus bigger containers mean more oxygen, more candles mean less oxygen for each given no increase in air supply. Carbon dioxide is mentioned first as a product of combustion rather than smoke.

Although the candle physically melts, it is also chemically consumed. Advantages of the real experimentation are more diverse and advantages of the computer are more discerned. None of the students we talked to, however possessed a well developed idea about the chemical processes involved in combustion. But

most students were able to produce averages, interpolate, predict and generalize from graphs. Students used graphs to interpolate and data tables to predict, and they appreciated the predictions and graphing features of the computer.

Such processes are open to systematic development in junior classes, and the student worksheets and interview data suggest that the 12 year olds, at least, could profit from systematic instruction on this topic -- a fundamental part of the larger topic of the particulate nature of matter.

Students were also aware of the role repeated trials play in establishing patterns in nature, of the importance of accuracy in measurement, and of the role mathematical procedures can play in helping to classify and represent those patterns. These students responded in a lively and engaged way when they were asked questions about these matter in class either by their teachers or the investigator. These whole class responses tend to support the conclusion that the responses of the individuals interviewed were not atypical.

Computers and Conceptual Change. Students can profit from their computer experiences. The results we have just considered suggest this. Students can use computer simulations for example to explore their pre-conceptions about the world. They can use the computer as an instrument which reflects back to them the consequences of their way of approaching problems. It is in the sense of "back-talk" that I want to develop ideas about conceptual change based on the studies we have just considered.

As we have seen, students do not approach school tasks empty headed. On the contrary, they have ideas about how to probe problems they encounter in order to see if they are patterned. They have ideas about how to explain the patterns they discover. Recall how some students gathered data about the effect of container size

on flame life. They entered values in order to determine if there was a connection *at all* between container size and flame life; not just to find out *what* the connection was which was the task set for them. They imposed their own agenda: find out if the system has a pattern at all. (Hawkins, 1985; Mawby, 1981) Thus patterning itself became the task. The computer simulation made it relatively easy to pursue the study of patterning, because students could gather data quickly without having to reset the experiment, and without encountering the errors that could creep into actual experiments due to faculty experimental procedure.

While the actual experiment provides a very satisfactory basis for gathering data about the nature of the connection between size and flame life, the computer provides a better basis for exploring patterning, but only if the program can simulate the variability of results that accompanies actual experimentation. Mathematically generated patterns with no variance simply do not reflect the reality of experimentation. Patterns can be discerned, not because of some mathematical exactitude in the data, but because of an emerging awareness of pattern. Students should be prompted to make explicit in their emerging ideas about patterning. To do this they can be asked to predict the next result, as they did in the flame life program.

We asked some of the students how they predicted the next value. They weren't sure how they did it as their comments suggest:

I had to guess. Maybe I remembered what my time was for the last time [I did the trial]. [10 year old.]

It goes into a pattern. [10 year old.]

[Prediction came] from your mind. I just guessed them. [10 year old.]

By looking at what your last time was, or looking at your graph. [11 year old.]

By knowing what was going on. If you had 5 candles, and the time was 11, you'd know it would be lower if you had 4 candles because it would take up more oxygen. [11 year old.]

If the size of beaker and the candles are the same but there are two candles I'd cut it in half. [When I did it] it was pretty close. [12 year old.]

I did it by how big the jar was, or just estimating. I knew how long one candle would burn It was surprising when you added a second candle how quickly it [went out]. [12 year old.]

You could usually tell if it was the size of the beaker. After a while we figured out how to get it exactly. [12 year old.]

The younger students "guessed." But notice how the older students approached prediction. They used their ideas about the nature of the pattern as a clue to prediction. One went beyond that to prediction based on a theory about what was happening.

However, if there is little or no variability in results, students do not receive apparently disconfirming or at least anomalous results which might upset their idea about what is going on. They easily may see the pattern but gather a false impression about it. Without variability in the data they receive the false impression that the pattern is "out there", rather than imposed by them. It is only in the mind's eye that a pattern exists -- such as a pattern has to be imposed on variable data. Thus it is very important that the simulation exhibit variability. At the same time the teacher or the program has to help students cope with the idea that there is reason to think a pattern exists even if that data does not perfectly conform to it. The power of preconception is likely to be sufficient to overcome irregularities in the data as long as the general tendency of the data conforms to expectations. When students do not encounter expected patterning they impose it anyway. There is evidence for this tendency in our studies of FLAME LIFE.

The back and forth gathering of data we saw in the case studies, and the repeated trials using the same values for container size, can now be thought of as ways students check whether or not their preconceptions can be confirmed. Students confronting a task in school likely expect to find patterning, but have to confirm this, and if necessary re-confirm it. We can see this in the very way students gathered data in the cases we have considered.

On the whole the students predicted accurately computer generated values for flame life when varying container size. However, notice the surprise expressed by one student at the rapid reduction in flame life when two candles are used instead of one. Her graph not only portrayed an inverse relationship, but an exponential one as well. Two candles go out more quickly than you would expect had you a linear model in mind. Clearly she had a linear model in mind.

The lack of effect of the height of the candle on flame life surprises students the most. The air (oxygen) supply model they hold leads them to think that the increased bulk of candles will make a difference to the bulk of air supply available and hence to flame life. They are right on the first count, but not right on the second. Although the effect is there, in theory, in practice it is smaller than can be detected experimentally. Determining when one candle is out in reality is difficult, and it introduced considerable variability into the results.

Students expect the smaller candles to go out sooner; but in the simulation they do not. Some think of the effect small and wonder why the program does not measure flame life in 1/10's of seconds, especially since they used their digital watches earlier to measure flame life in the classroom. One student simply said that he found the the height had made a difference in the simulation, even though it hadn't. He had imposed this pattern on the data. Students expect to see a difference. In their mind's

eye, the reduced bulk of oxygen should give rise to reduced flame life. Student comments suggest that they still believe that the bulk theory. They expressed their surprise when the simulation did not confirm their preconception. Earlier experiments with container size and numbers of candles had come out as expected, but not height.

Getting to the Bottom of Things

Students analysed the simulation. How realistic was the simulation? Students asked these questions of each other during their work at the computer. These questions spring naturally from their classroom and computer experience but they require a classroom in which questions like these can be asked; in which it is important to get to the bottom of things. Doing this kind of work is a way in which the teacher could express the importance of getting to the bottom of things; of the value of persistence, risk taking, and speculative thought. That is the way simulations like FLAME LIFE could contribute to conceptual change; not alone but in conjunction with a teacher interested in using the possibilities of the computer simulation. Critically looking at the simulation is a way of getting to the bottom of things, by seeing how adequate are existing conceptions of scientific theory and method and by showing each other how much they care about getting to the bottom of things.

Students bring to phenomena preconceptions the nature and the function of which they may not be aware. They do not come empty headed to experience, even though they may think they do, or be told so. On the contrary they bring to experience preconceptions based on their own need to make sense of the world (White, 1992).

~~One~~ way children make sense of the world is to see patterns in everyday experiences. School encourages this. Weather records are kept, for example. The cycle of seasons is observed and they are celebrated. Children bring their own ideas

to these patterns. These organizing conceptions which are prior to experience, are the ideas out of which experience is constructed, and which makes possible safe and satisfying passages in the world. Unless students understand their own conceptions, they have no way of assessing how useful alternative conceptions might be. While the computer can provide appropriate challenges, it is the teacher who has to help students understand what those experiences signify. How this can be done cannot be anticipated in advance since what the teacher says to the student depends on what conceptions each student bring to his or her experience. Thus the computer itself cannot be relayed upon to help students make sense of this experience since it cannot be programmed in advance to anticipate how different students will make sense of their experience. Only teachers can help students see the consequences of their ideas, but the computer can be a powerful aid if used in the right way.

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